Eelgrass Monitoring in Puget Sound: Overview of the Submerged Vegetation Monitoring Project

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Abstract

Eelgrass (*Zostera marina*) is monitored in many regions as an indicator of nearshore habitat quality by comparing maps of resource abundance and distribution over time. In Puget Sound, there are environmental and scale-related barriers to using traditional systematic mapping methods for monitoring eelgrass. The study area is extensive (almost 4000 km of shoreline), and it is difficult to survey this subtidal species that can grow to a depth of >30 ft MLLW with traditional methods (divers, aerial photography, acoustic techniques). In summer 2000, the DNR initiated the Submerged Vegetation Monitoring Project as a nearshore habitat component of the Puget Sound Ambient Monitoring Program. The four goals of this project are to:

(1) Capture temporal trends in eelgrass abundance and distribution in Puget Sound.
(2) Summarize temporal trends over Puget Sound and subareas.
(3) Monitor vegetation parameters that are strong indicators of eelgrass extent and quality.
(4) Link stressors to abundance and distribution. Six "core" sites will be sampled each year, and the remainder of Puget Sound will be sampled using rotational random sampling with partial replacement. This sampling plan addresses the two conflicting goals of sampling for status over large spatial areas (inventory) and capturing temporal trends (monitoring).

Background

Eelgrass beds are an important habitat type in Washington. They provide substrate for many small organisms that are food for larger species, habitat for migrating salmon, food for black brant and other waterfowl (Simenstad and others 1988; Phillips 1984). Eelgrass also provides a source of carbon into nearshore habitats and stabilizes the sediments (Phillips 1984).

Eelgrass and other species of seagrasses have been declining world wide, especially in areas of intense human development (Walker and McComb 1992; Short and Wyllie-Echeverria 1996). Anthropogenic stresses on eelgrass include activities that disturb the beds directly such as dredging and anchor scars, or indirect activities that reduce the light over the plants, such as over-water structures or reduce the clarity of the water column and thus the ability for light to penetrate into the water column, such as runoff (increased turbidity) or nutrient addition (facilitating algal blooms). The deeper edges of the beds are most vulnerable to these stressors. Mumford and others (1995) called for the subtidal populations to be surveyed as they may be indicative of changes in water quality.

The need for state-wide data on eelgrass status and trends has been long known (Mumford 1994; Mumford and others 1995; Wyllie-Echeverria and others 1995; Lynn 1998). These data are integral to developing effective management of this resource (Fresh 1994; Mumford 1994). At this time, resource agencies have adopted a "no net loss" policy. A monitoring component is needed to assess if this policy is being realized (Fresh 1994). This has led to the creation of the Submerged Vegetation Monitoring Program, which attempts to quantify the state resource and its change over time.

This paper outlines program's goals, and reviews some rationale of the program's design. Details on the methodology used in this monitoring program and some preliminary results are in Norris and others 2001a in this volume.

Eelgrass in Puget Sound: Current Knowledge

A few statewide estimates of eelgrass coverage in Washington State exist. Here are three examples of estimates covering the area from the Canadian border, south to southern Puget Sound, and west to Ediz Hook in Clallum County. The estimates of the shoreline containing eelgrass range from 21% to 43.9%. Each study employed a different methodology explaining some of the variance. However, the ShoreZone estimate is much higher because it distinguishes shorelines with patchy eelgrass (26%) and shoreline miles with continuous eelgrass (18%). It is our goal to refine these estimates using the data resulting from this project.

Table 4. Three estimates of the percent of the shoreline containing eelgrass in Puget Sound.

Study	Reference	Estimate
Probability Based Estimation 1995	Bailey, and others 1998	23.4% ±2.8%
Puget Sound Environmental Atlas	Evans-Hamilton, DR Systems, 1987, digitized from the Coastal Zone Atlas 1980.	25.1%*
Washington State ShoreZone Inventory	Nearshore Habitat Program, 2001	43.9%

* Analysis of eelgrass layer completed by A.R. Bailey.

Many studies and surveys of eelgrass are done on small scales throughout Puget Sound. These include studies for recreational docks and larger scale projects assessing the eelgrass resource at a county level. The data collection method and scale of each project is different and difficult to use for a statewide estimate of eelgrass. However these data could be useful if there was a standard way to integrate the datasets into a statewide coverage or map.

In Puget Sound, long-term trends of the extent of eelgrass meadows are not known. Where comparisons of present and historical eelgrass areas have been made, the acreage has apparently decreased in some areas and increased in others (Thom and Hallum 1991). The data from the Submerged Vegetation Program will provide information on trends of eelgrass beds for the years data are collected.

Project overview

The Nearshore Habitat Program represents the Washington State Department of Natural Resources (Natural Resources) as a component of the Puget Sound Action Team's Puget Sound Ambient Monitoring Program (PSAMP). The PSAMP assesses environmental conditions of Puget Sound and impacts to its natural resources from human activities. The Nearshore Habitat Program focuses on spatial patterns and temporal trends in nearshore areas. The initial challenge is to identify appropriate environmental indicators of nearshore habitat health and determine how these indicators can be monitored over space and time with current funding. Submerged aquatic vegetation is one indicator of nearshore habitat health and we have contracted with Marine Resources Consultants to design a monitoring program for submerged vegetation (eelgrass, *Zostera marina*) and collect the first year of data. Separate projects are underway to capture broad spatial patterns in intertidal vegetation types (see Berry and others 2001a; Bookheim and others 2001, and Harper and others 2001a in this volume) and to monitor canopy-forming kelp populations (see Berry and others 2001c, this volume).

Eelgrass, as well as other seagrass species, have been used as indicators in other areas of the world and can be tied to management goals and priorities. These rooted plants, once established, become permanent features of the submarine environment and respond with decreases in density (shoot abundance) and aerial extent when the environment becomes less habitable. These disturbances can be natural (for example, coastal uplift, bioturbation, disease) or human induced (e.g. eutrophication, dredging), (Hemminga and Duarte 2000). This characteristic allows an analysis of human impact to a coastal water body because reductions in water clarity and submerged land removal can be directly linked to human activities. For example, Orth and Moore (1983) using time series data from the monitoring of submerged vegetation (*Z. marina* and fresh water vascular plants), described the link between watershed activities that decrease water clarity and, in turn, submerged vegetation cover and the overall productivity of the Chesapeake Bay. This finding and action from the Chesapeake Bay Estuary Program resulted in the enactment of legislation to restrict activities that lead to reductions in water clarity, reversing the trend of vegetation loss and beginning the Chesapeake Bay on a path toward recovery (Dennison and others1993). While the condition of the Puget Sound submerged vegetation zone may not be as threatened as observed in Chesapeake Bay, the Submerged Vegetation Monitoring Program will provide:

(a) A baseline estimate of eelgrass shoot abundance and aerial extent in subtidal as well as intertidal regions.
(b) An early warning system should conditions in the eelgrass, a vital component of the nearshore vegetation zone, begin to deteriorate.

SUMMARY:

- Eelgrass Monitoring (*Zostera marina*, not *Z. japonica*).
- Designed a program appropriate to our large study area
- Data are collected at high resolution for plant and site characteristics
- Sampling design and statistics will allow us to extrapolate results over larger areas.

Successful monitoring programs not only assess the status and trends of the indicator organism, but link it to stressors and disturbance. Therefore, we divided this broad project into several phases and have only implemented Phase 1 to date. With increased funding and/or collaborations, we will address stressors and disturbances in the second and third phases.

<u>Phase 1:</u>

Monitor broad scale submerged vegetation (eelgrass) trends in distribution and abundance in Puget Sound at sampling sites.

<u>Phase 2:</u>

Expand monitoring to include other submerged vegetation types
Monitor across gradients of stressors e.g. shoreline development.
Increase the number of sites.
Measure long-term historic changes.

<u>Phase 3:</u>

Develop programs that monitor submerged habitat at higher spatial and temporal resolutions.
Gather experimental evidence on cause-effect interactions to build cause and effect models.
Address functionality, habitat quality and wildlife usage.

Our current project, addressing Phase 1, has four main goals:

1. Capture <u>temporal trends</u> in submerged vegetation abundance and distribution, specifically eelgrass, in Puget Sound. At a minimum, comparisons of trends over multiple years must be possible. In order to capture yearly trends, the monitoring protocol must minimize variation due to seasonal differences. While the ability of the monitoring protocol to detect temporal trends over small areas is important, it must be balanced with the need for general monitoring results over large areas.

2. Summarize temporal trends over large areas. Synoptic assessment with current technologies is prohibitively expensive due to the large study area, yet the monitoring protocol must allow for summarizing trends over large areas. The project plan must define site selection criteria that identify sites that are representative of the entire study area. In addition to summarizing data over the entire study area, the protocol must also allow for analysis of trends over subareas that are defined by considering environmental and/or human use factors. The numbers of sites and statistics chosen must be robust enough to allow some statistically sound conclusions to be drawn about eelgrass beds at these two scales. The ability to summarize trends over smaller spatial areas is desirable, but it is secondary to capturing temporal trends.

3. Monitor vegetation parameters that are strong indicators of the extent and quality of nearshore vegetated habitat. The choice of vegetation parameters to measure (e.g. maximum depth, density, extent of beds, biomass, leaf area index, patchiness) determines the types of conclusions that may be drawn from the results (Neckles 1994). At a minimum, eelgrass (*Zostera marina*) must be monitored and mapped to its full bed extent including subtidal and intertidal extremes. The protocol must consider the degree of change in submerged vegetation that can be detected with the methods chosen.

4. Consider stressors. A major focus of the PSAMP is to correlate environmental trends with stressors to the greatest extent possible and to differentiate natural and anthropogenic stressors. The monitoring project must consider environmental and anthropogenic gradients. At a minimum, temporal trends in submerged vegetation must be considered along some continuum of pristine/degraded conditions. Collecting other environmental parameters that are correlated with eelgrass condition could greatly increase the usefulness of the data set (e.g. salinity, temperature, turbidity, epiphyte load nutrients).

The following sections of this paper will outline how our current project plan addresses these project goals.

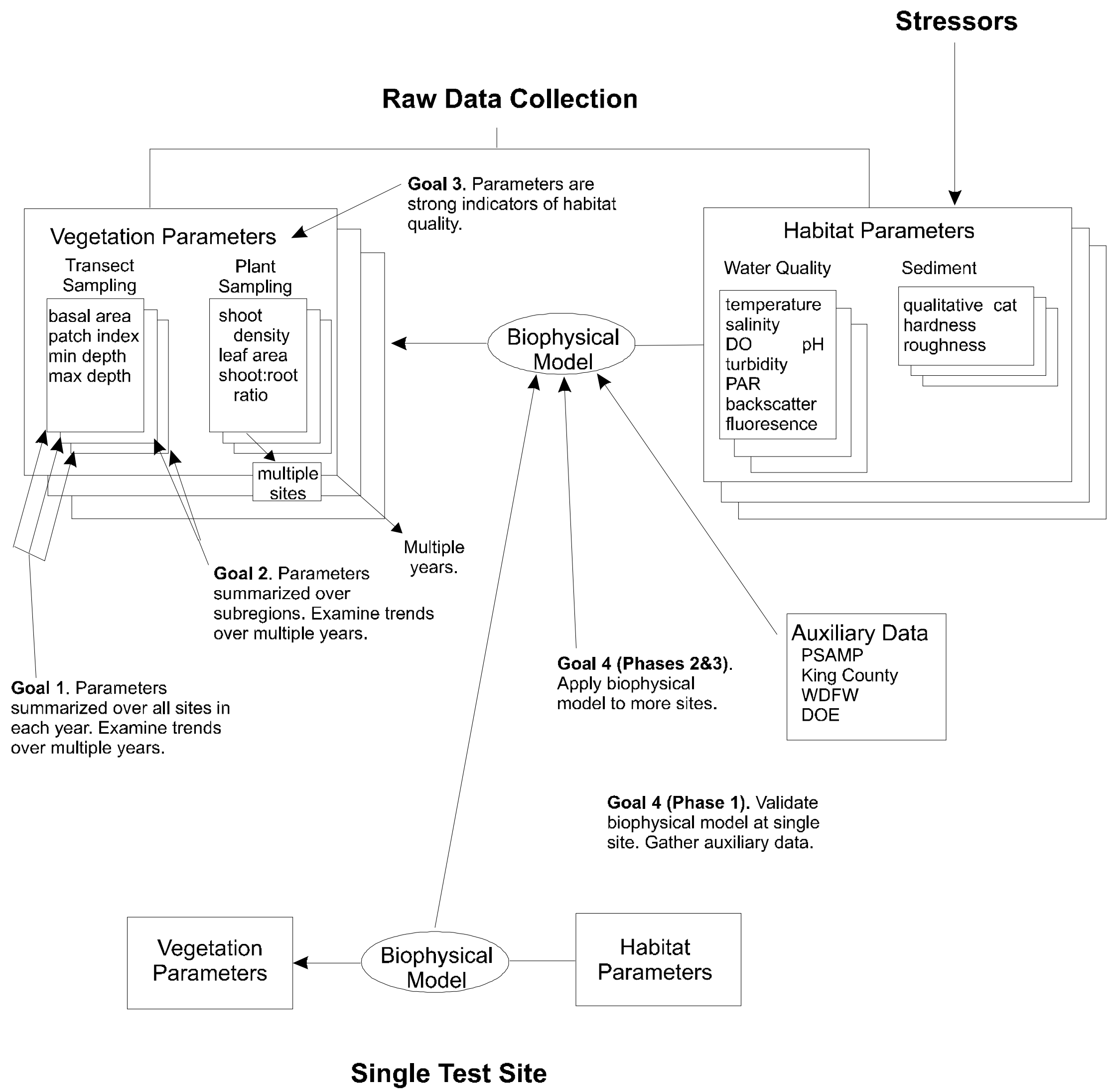

Figure 1 Diagram illustrating the relationship between the goals and the project plan.

Goal 1: Capture Temporal Trends: Mapping vs. Monitoring

In order to best choose our methodology we reviewed the difference between mapping and monitoring as each has strengths and weaknesses for resource assessment. Most mapping projects are site-specific, useful for assessing the spatial extent (status) and identifying patterns of a feature or resource. And they are scale dependent, both in data collection and data use and application.

For other projects, the Nearshore Habitat Program used airborne remote sensing to map intertidal vegetation. The Puget Sound Intertidal Habitat Inventory 1995 and 1996, classified intertidal vegetation into one of eight vegetation categories, including eelgrass. One of the shortcomings of this methodology is the inability of the sensor to detect eelgrass under the water′s surface. This technology precludes using this sensor for collecting data on the deep edge of the eelgrass beds. But more importantly, the positional accuracy of +/- 40 feet (Ritter and others 1999) does not permit accurate trend analysis as most of the beaches in Puget Sound are narrow features often less than 40 in width.

Many projects use mapping techniques for change detection and trend analysis. Mapping protocols developed by the Coastal Remote Sensing Program, of National Oceanic and Atmospheric Administration

(NOAA) rely primarily on color aerial photography of benthic vegetation. The protocol (updates available at http://www.csc.noaa.gov/crs/bhm) stresses the importance of using optimal conditions and outlines project scooping, accuracy assessments and analysis and presentation of the data. In the Chesapeake Bay region, under the Chesapeake Bay Agreement, aerial imagery data has been collected and analyzed for many years for use in trends analysis of aerial coverage (VIMS 2001). In Puget Sound, aerial photographs have been used for several mapping projects but not necessarily change detection. The main difficulty with this technology is the resolution of the lower edge of the eelgrass beds. In some areas of Puget Sound, eelgrass can grow to a depth of 20 to 30 feet (Norris unpublished data; Thom and others 1998) and the lower edges of the beds are not detectable using aerial photographs.

Monitoring studies using scientific sampling can be specifically designed to assess changes in a resource over time. The great value of scientific sampling is the ability to make useful inferences about a population from data collected on a sample from that population. Our project is designed to detect trends over time, and will allow us to make estimates of eelgrass abundance over our large study. We can calculate estimates of error, which is always associated with scientific sampling.

Sampling Design

The objective of our sampling design is to provide valid inferences to the Puget Sound-wide population of eelgrass on an annual basis (status) and over time (trends). Sampling for status implies random sampling from the entire population each year; sampling for trends sampling fixed sites overtime the sites become less and less representative of the population inference (Skalski 1990, Overton and Stehman 1996).

To balance these conflicting goals (status vs. trends) this protocol uses a rotational sampling design specifically devised for estimating the status and trends of ecological populations (Skalski 1990). Rotational designs are an ideal mix of strategies that optimize the joint desires to accurately estimate the correct status of the populations and accurately and precisely estimate changes over time. In rotational designs, a fixed fraction of the sampling sites is replaced annually with a new selection of locales. The precision and estimates of eelgrass abundance are actually improved over time as subsequent years of data are used to update site-specific estimates. We will replace 20 percent of the samples each year with new sample sites.

We have chosen linear transect sampling methodology for collecting samples and will collected the data using underwater video. The details are outlined in Norris and others 2001a in this volume, and in Norris and others 1997.

Goal 2: Extrapolate over Large Areas—Site Selection

Sampling Frame

This project has the unique challenge of assessing a variable habitat type over a large area, the Puget Sound area. There are approximately 2400 shoreline miles from the Canadian border to the western edge of the Straits of San Juan de Fuca. The sampling frame in this area was further defined to be the area of lower intertidal to the lowest depth eelgrass occurs at each site termed the eelgrass zone. We used two available GIS bathymetric contours to spatially delineate our eelgrass zone, the –20 foot contour (WDFW) and the Water Level Line (DNR) which is approximately mean high tide.

Eelgrass beds in Puget Sound appear in two basic forms: fringing beds that exist as narrow features along the shoreline, and beds that are longer than wide that range in size from 21 acres (Picnic Cove on Shaw Island) to vast beds such as Padilla Bay or Skagit flats.

These two types of beds are sampled differently and treated differently when calculating estimates of basal area, see Norris et al. 2001a and 2001b.

Core sites

Core Sites, sampled each year, were chosen to represent the wide variety of eelgrass habitats found in Puget Sound. They are spread around the state, and are of varying shapes and sizes. This was our opportunity to hand pick some sites which will provide opportunities for more in depth studies as we move into Phase 2 and Phase 3 of the project.

Table 1. Description of core sites, sampled yearly in the Submerged Vegetation Monitoring Project.

Site	County	Type	Size (acres)
Padilla Bay (middle section)	Skagit	Flat	2840
Jamestown, Straits of Juan de Fuca	Clallum	Flat	2358
Picnic Cove, Shaw Island	San Juan	Flat	24
Lynch Cove, Hood Canal	Mason	Flat	1482
Burley Spit, Carr Inlet	Mason	Fringe	No area estimate
Dumas Bay, Federal Way	King	Fringe	37

Regions

Five regions were defined loosely based on oceanographic sills and circulation patterns to allow for a regional clustering of estimates. The white area named south Puget Sound was not sampled by this project because no eelgrass (*Zostera marina*) has been observed here (Nearshore Habitat Program 2001; Dan Penttila pers. comm.).

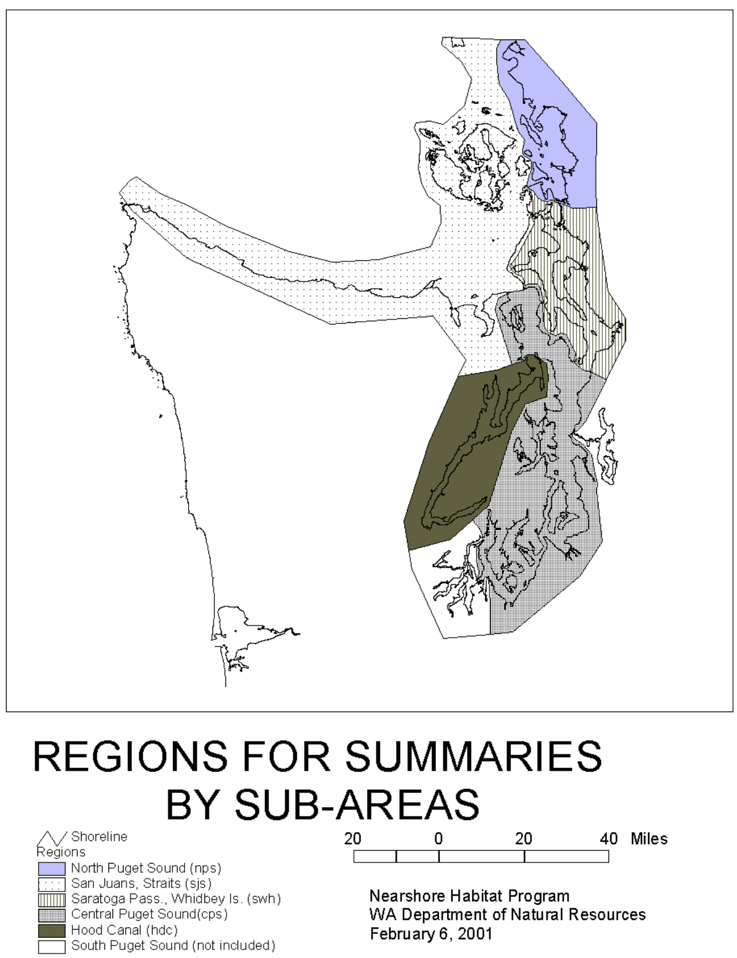

Figure 2 Regions defined for describing data on regional scale.

Goal 3: Selection of Vegetation Parameters to Monitor

Vegetation parameters to monitor were selected by three main criteria: strong indicator of eelgrass status and trends, low seasonal variation, and cost-effective to measure.

Basal area coverage

Basal area coverage is defined as the number of square meters of substrate that has eelgrass growing on it. We are measuring presence (at least one shoot/m^2) and absence of eelgrass.

The amount of this important habitat type is a critical piece of data for scientists and managers. Consequently, effective management of his habitat type depends on the data available on eelgrass cover that exists and the changes in the resource amount over time. This parameter can be computed at the site, region and Sound-wide levels. These data will allow researchers to determine if (1) the eelgrass resource is increasing, declining or stable over time, and (2) what regions of the Puget Sound are showing the greatest changes in abundance.

Maximum/Minimum Depth of Eelgrass

The maximum and minimum depths of eelgrass refer to the shallow and deep-water boundaries of eelgrass beds. We oriented the transects perpendicular to the shore. For each of these transects, a maximum and minimum depth of eelgrass was recorded, an average of 12 for each sampling site. We will calculate descriptive statistics (range, mean, variance) for minimum and maximum depth measurements.

The distribution of eelgrass across a bathymetry gradient is dependent on both the amount of time the plants are exposed to air in the shallows and the quality and availability of light penetrating through the water at the deeper edge. Many studies have reported a negative correlation of bottom depth with light quality and quantity. Dennison and others (1993) discovered that system wide trends in the lower limit of submerged vegetation (including eelgrass) over time can be a predictor of ecosystem health.

Analysis of this parameter will be most useful for trend analysis at individual sites. Preliminary data show that the maximum and minimum depth patterns are complex and variable on a regional scale.

Mean Shoot Density

We defined this variable to be the total number of shoots divided by the basal area coverage. Shoot densities can change in response to seasonal and stress gradients and are therefore indicators of environmental change at local and regional scales (Phillips and Lewis 1983; Kentula and McIntire 1986; Olesen and Sand-Jensen 1994). Documenting shoot density changes is a common feature of eelgrass investigations and thus comparative analysis using data from the literature is possible (Neckles 1994).

Mean shoot density will be computed only at the site level. Shoot density varies with site, substrate, depth and other biological factors making it less useful as a regional statistic.

Patchiness Index

A quantitative measure of “patchiness” (referred to as “grain” by Pielou 1977) can be computed by considering an eelgrass bed as a two-phase mosaic. Areas with eelgrass are called patches and those without are called gaps. Beds with high patchiness have many transitions from eelgrass to no eelgrass. Beds with low patchiness, or higher homogeneity, have fewer transitions between the two phases. We define the patchiness index to be the number of transitions per 100m of straight-line transect length.

Basal area describes how much of the substrate is covered by eelgrass but does not provide information on the distribution within this vegetated zone. The homogeneity of an eelgrass bed is interrupted by many disturbances: anthropogenic factors such as boat anchors and dredging activities; or biological agents such as disease, competition by green algae etc. A negative trend in this index’s trend at a site or region could indicate the need for an evaluation of site-specific disturbance agents. Evaluating the cause of increased patchiness, however; it may be difficult.

a)

b)

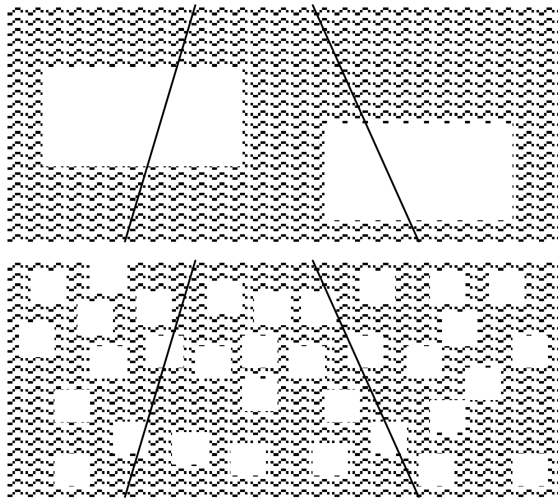

Figure 3 An illustration of plots that have a) low and b) high patchiness indices.

Leaf Area Index

Leaf Area Index (LAI) is a measure of leaf area per substrate area, ie, mean shoot density multiplied by the surface area per vegetative shoot per substrate area. This index quantifies and estimates the amount of aerial habitat available to the organisms that live on the leaves. Because LAI integrates the value of leaf area and shoot density, the index is potentially more sensitive to environmental stress than a parameter such as leaf width (Neckles 1994). LAI statistics will be computed only at the site level.

Wet-Weight Shoot:Root Ratio

Wet-Weight Shoot:Root Ratio (SRR) is determined by comparing the weight of the shoot material with the root/rhizome material and creating a ratio of their relative weights. SRR will be computed only at the site level.

Table 2. Vegetation parameters and the scale of analysis used in the Submerged Vegetation Monitoring Project.

Parameter	Variables	Definition	Scale of Analysis
Acreage	Basal area coverage in m^2	At least one shoot / m^2	Site, Region, Puget Sound
Maximum/Minimum Depth of Eelgrass	Range, mean, variance	Depths at deep and shallow edges of eelgrass beds	Site
Shoot Density	Mean	Total number of shoots / by basal area coverage	Site
Leaf Area Index	Mean density, surface area/meter index	A measure of leaf area per seabed area, mean shoot density multiplied by mean leaf area per shoot.	Site
Shoot to Root Ratio	Mean	Wet weight of shoot material divided by wet weight of root material	Site
Patchiness Index	Index calculated	Number of transitions between a two phase mosaic	Site

Goal 4: Consider Stressors

Environmental parameters

Data on environmental parameters will be collected at each site. Water column profiles (i.e. measurements every meter) include the following parameters: temperature, salinity, conductivity, dissolved oxygen, pH, turbidity, and Photosynthetically Active Radiation (PAR). Although seawater properties are constantly changing, collecting snapshot data at each site may provide clues to significant water quality differences between regions of Puget Sound.

Table 3. Environmental parameters measured in the Submerged Vegetation Monitoring Project.

Parameter	Accuracy	Resolution
Position (Lat/Lon)	± 3 meters	± 0.000001
Corrected depth	± 0.5 feet	± 0.1 feet
Temperature	± 0.1 C	± 0.01 C
Salinity	± 0.2 ppt	±0.01 ppt
Dissolved oxygen	± 0.2 mg/L	± 0.01 mg/L
Turbidity (NTU's)	± 5% of range	±0.1
Photosynthetically Active Radiation (PAR)	± 5% of reading	± 1µmols^{-1} m^{-2}
Light parameters, backscatter and florescence	na	na

Biophysical Model

Data for calibrating a biophysical model developed by Zimmerman and others (in preparation) was collected at one of the core sites—Dumas Bay. Preliminary results are outlined in Norris and others 2001a. The goal of the model is to be able to eventually map eelgrass distribution using GIS as a function of submarine light and CO_2 availability. The integrated biophysical/GIS model, when populated with site-specific data, will be able to predict changes in potential eelgrass distributions as a function of climate change and anthropogenic alteration for a specific coastal environment.

Next Steps

Analysis of the results from the first year will be completed in the spring of 2001. We will use these results to help refine monitoring project methods. To give us a broader perspective, a group of international scientists will review the project results. These comments will be incorporated into the methodology for the next sampling season.

We will then begin to analyze the data to identify spatial patterns. The rotational random sampling design allows us to stratify, after sampling, using various spatial or environmental criteria. Thus, regional, spatial patterns can be identified and eventually linked to management issues. Other site-level or regional data sets may be compared to statewide data to provide context and basis for comparison. However, for statistical comparisons of various eelgrass parameters, the data must be collected using the methods outlined in this project.

As we collect subsequent years of data, we can begin trends analyses to determine how the resource abundance is changing over time. In addition, several data sets exist that contain historical eelgrass data. This sampling methodology should provide the framework to resample some of these areas and determine quantitatively or qualitatively the present status of the resource in these areas.

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